Acoustical design of hospitals: Standards and priority indexes

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INTRODUCTION

Improving acoustic conditions will result in a shorter or better hospital stay for patients? And will it result in a better performance of medical teams? Possible answers to these questions can be derived from scientific literature and confirmed by recent experiences here reported.

Unfortunately the patients' stay in hospital areas is often characterized by long periods of inactivity where they spend their time doing nothing and so becoming more sensitive towards environmental quality and comfort of their staying. In his/her hospital lifetime a patient can find a very short number of distractions as compared to normal life.

This paper refers to a methodological approach that aims to reduce noise in designing new hospital settings, with special attention to the most sensitive areas.

Starting from a review of international studies and papers on acoustic conditions in healthcare buildings, as well as on international standards and national provisions, a group of architects, engineers and acousticians with different backgrounds and affiliations, have joined with medical doctors working in and managing hospitals. The main aim of the group is to produce proposals for a guideline for acoustic comfort design of sensitive areas and activities, relating to new buildings and refurbished ones.

Models and indexes for the identification of hotspots and critical factors in health structure acitivities (and consequent priorities) have been investigated with special attention to those based on time of exposure and severity of illness. Indexes have been proposed and tested, giving, as first result of the research, information about acoustical comfort or discomfort in existing hospitals.

METHODS

In the Italian experience, according to European and National laws and standards, Public Administration and Control Authorities ask the designers of new healthcare buildings for careful and accurate studies of the acoustic behavior of new settlements, considering problems of compatibility in areas with different destinations.

The predictive assessment of environmental noise pollution is obtained from the correct estimation of the impact of plants, activities, traffic and other sources and then adapting algorithms provided for.

But a healthcare building is a system of sources and receivers of noise pollution itself; there are rooms and areas where sources and receivers must co-exist and the annoyance is produced by noise generated inside the area combined with noise coming from outside.

In 1992 the United Nations Conference on Environment and Development of Rio de Janeiro established the principle of sustainable development. From the diffusion of this cultural approach derives the need of a definition of rules and procedures for the correct designing of buildings and living spaces. Every building could have been designed in such a way to be comfortable and non-inducing pathologies like Sick Building Syndrome (SBS), also called Tight Building Syndrome (TBS), and Building Related Illness (BRI). The final aim for designers must be to provide building occupants with a healing environment free of disruptive levels of sound.

In this context, wellness and eco-compatibility in the designed buildings are considered also in terms of simultaneous reduction of noise breakings in. Thus healthcare facilities represent a challenge and an opportunity in the development and implementation of sustainable design, construction and operations practices.

Several methodological approaches consider the assessment and the improvement of acoustic atmosphere and acoustic comfort in internal areas, where sensitive receivers (patients) usually live, starting from information about territory and structure of buildings, considering case scenarios with various levels of complexity, due to different compositions of sources and receivers. The structure of buildings and the related structure-borne sound propagation in the internal areas can be analyzed using the ISO methods and models concerning the acoustic properties of buildings.

A general designing scheme starts from the acoustic climate “ante operam” and consider: acoustic analysis of inner and external sources; measurement and computation of acoustic impact on the inner and external receivers; analysis of acoustic requirement of the building; final designing.

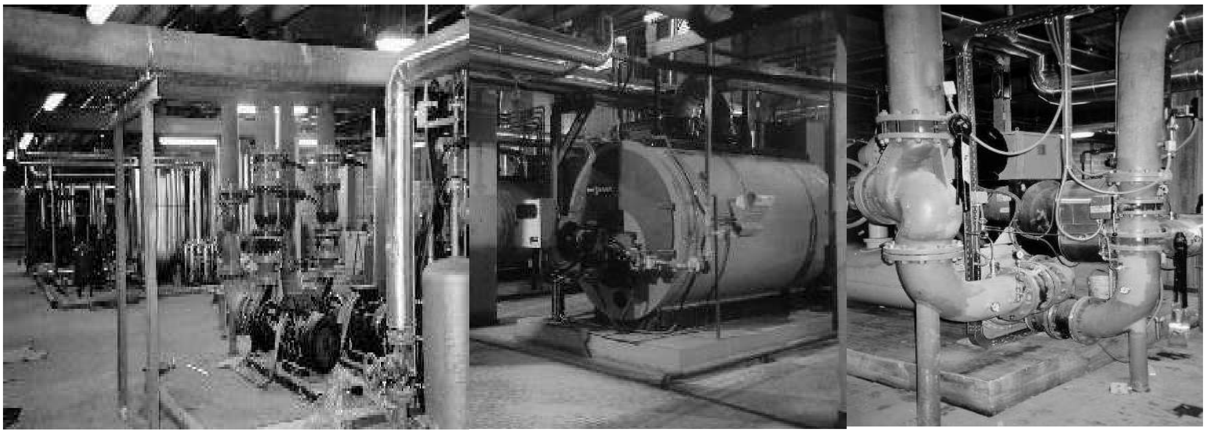


Figure 1: Example of internal sources of a General Hospital

Noise impact of a new building on the acoustic atmosphere of the surrounding receivers has to be measured and analyzed in advance. Italian City Administrators ask for noise impact prediction, as a necessary preliminary document, to authorize each potentially pollutant activity or building. The International Standard references (ISO 8297 for the determination of sound power levels of multisource industrial plants, ISO 9613-2 for the method of calculation of the attenuation of sound during propagation outdoors) can be considered.

The analysis of the acoustic quality of the building has to be carried on measuring and calculating all the significant parameters, such as Rw, Ln, w, D2m,nT,w also defined by the ISO standards.

This methodological approach brings to a view of the acoustic performance of a building, based upon the modeling of sources and receivers located inside and outside it.

In Table 1 the step by step sequence of activities that take to an acoustically compatible way of sensitive building designing has been schematically shown. It can be assumed as a minimum required roadmap for healthcare building designers

Table 1: The acoustical design procedure flowchart for a generic health care building

<table>
<tr><td colspan="4">ACOUSTICAL STUDY - ante operam assessment - simulations</td></tr>
<tr><td>A1
acoustical ante operam climate assessment in the interested area</td><td>A2
noise impact prediction of internal sources on internal and external potentially annoyed receivers</td><td>B1
noise impact prediction of outdoors sources on internal potentially annoyed receivers according to designed layout</td><td>B2
prediction of the acoustical behavior of wall, ceilings and other building elements</td></tr>
<tr><td colspan="4">ACOUSTICAL DESIGN - corrections</td></tr>
<tr><td colspan="2">A
DEFINITION OF ENVIRONMENTAL ASSESSMENT OF BUILDING</td><td colspan="2">B
DESIGN OF ACOUSTICAL OPTIMISATION OF INNER SPACES</td></tr>
<tr><td colspan="4">ACOUSTICAL TEST - post operam assessment - measurements</td></tr>
<tr><td>A1
acoustical post operam climate assessment in the interested area</td><td>A2
noise impact assessment of internal sources on internal and external potentially annoyed receivers</td><td>B1
noise impact assessment of outdoors sources on internal potentially annoyed receivers according to designed layout</td><td>B2
acoustical analysis of structure and materials acoustic behavior of wall, ceilings and other building elements</td></tr>
<tr><td colspan="4">ACOUSTICAL CERTIFICATION - qualification of building</td></tr>
<tr><td colspan="2">A
COMPATIBILITY WITH ENVIRONMENT</td><td colspan="2">B
COMFORT OF INTERNAL AREAS</td></tr>
</table>

Also considering the contents of recently published documents and guidelines like Design Guidelines for Hospital and Healthcare Facilities, drafted by Technical Committees for Architectural Acoustics and Noise of the Acoustical Society of America, it is possible to make the reasons of environmental quality and high performance join together in a new healthcare units design philosophy. Not forgetting that besides the importance of acoustic comfort, there are the positive reasons of Music Therapy: good sound atmosphere may give to patients a physiological benefit but unfortunately, as we will see in the following paragraphs, it is often obscured by all the random (and often) unnecessary sounds that affect patients, even in the most noise sensitive units.

Recent UK measurement campaigns (see Boulter 2007) where the intention was to follow a typical patient journey through the hospital areas and activities, result that in all the locations visited, occupational noise dominates the environment. Daytime LAeq noise levels in ICU (from the patient side, very sensitive unit) were significantly higher (from 62 to 64 dB LAeq), mostly as a result of noise from the medical equipment.

CRITICAL AREA MODELS AND THEIR APPLICATION TO CASE STUDIES

A model based on a special index of acoustical sensitivity has been introduced by authors, see Luzzi (2004). It is a parametric index describing the need for particular conditions of acoustical comfort in sensitive areas of buildings. It is related to some other indexes representing time of staying inside the considered area (i.e. hospitalization) and the gravity of the potential annoyance (i.e. heaviness of noise exposure in a working place, severity of illness of patients in a hospital unit).

The acoustical criticity index **c** is a two variables functional, capable to represent with good level of approximation the need of acoustical comfort as a function of noise exposure time and annoyance severity.

The proposed model is supported by some series of statistical data collected from literature and directly tested by authors in contexts where noise-generated discomfort and annoyance had produced physiological or psychological effects and influenced performance and concentration. For example in sensitive areas of hospital, like intensive care units, a strong correlation between acoustical comfort and effectiveness of therapy has been found.

Acoustical analysis of internal critical areas with different destination and with different sources has been developed and standard values for constants and parameters have been found.

Sound levels measurements, frequency and statistic analysis, computation of indexes and definition of the acoustical environment during standard activities, study of acoustic quality of building, furniture, materials, means of sound propagation and radiation have been considered.

Case studies referred to different Italian hospitals can show the behavior of index **c** associated to a specific context (hospital area or activity), and its relationships with:

- **t**: time of patient-stationing in that area or of patient-subjection to that activity.
- **g**: gravity or severity of an illness or, more general, physiological state of the patient.

The aim is to represent the discomfort and annoyance level of each significant hospital area or activity using **c** index.

The functional **c = f (t,g)** has been defined and the combined dependence on **t** and **g** has been derived from simple mathematical equations that take in account the parametric relative weight of places and activities.

In some hospitals a group of sample contexts, like operating theater, recovery room, delivery room, intensive care unit, and others have been considered as applicative sceneries of the model. For each of them, statistical data about the standard time of patient staying in the unit and about the distribution of values of the main scoring systems, like GLASGOW and APACHE (Acute Physiology, Age, and Chronic Health Evaluation) have been found and put in the validation algorithm of the model, with the aim to find approximately the best fitting functional relationship **c = f (t,g)** in agreement with the two variables standard trend equations, summarized in Table 2.

Index c gives a measure of the acoustical comfort or discomfort of areas and activities carried on in healthcare buildings. The model has shown its efficiency above all in hospital contexts where hospitalization time of patients could be easily foreseen and activity cycles could be easily standardized. In all the case studies, time interval series, scales and units are chosen as the best fitting for the referred place or activity.

Table 2: Trend line equations for index **c**

Linear	**$c(t,g) = N_t M_t t + N_g g$** where: **$N_t M_t$** is the shape factor, derived from mean noise exposure level **N_t** and mean time of patient staying **M_t** **$N_g g$** is the intersection with **$t = 0$** axis, product between the intrinsic gravity **g** and annoyance constant **N_g** that represents the negative contribution to patient general conditions due to noise exposure. Symmetrically, **$c (t,g) = N_g M_g g + N_t t$** where the parameters can be defined in a symmetrical way too.
Polynomial	**$c (t,g) = k + k_1 t + k_2 g$** where: **$k_1$, k_2** are constants, adjusting the peculiar of t and g to the context sensitivity and **k** represent the intrinsic annoyance power (potential annoyance) of considered area or activity.
Logarithmic	**$c (t,g) = K \ln (t) + g$** where: **K** is a cumulative constant representing the context peculiar sensitivity and its potential power of annoyance and **g** is known. Symmetrically, **$c (t,g) = K \ln (g) + t$** where **t** is known

In Figure 2 a panoramic graph of hospital critical areas is shown. The scoring system APACHE II has been used to classify the variable g, representing the severity (gravity) index. A hotspot's scale and a priority scale have been found. The model applied to different areas and activities, gives a variety of response in terms of most representative equation among those shown in Table 2: logarithmic pattern equation has resulted to be the "best fitting" one for operating theater.

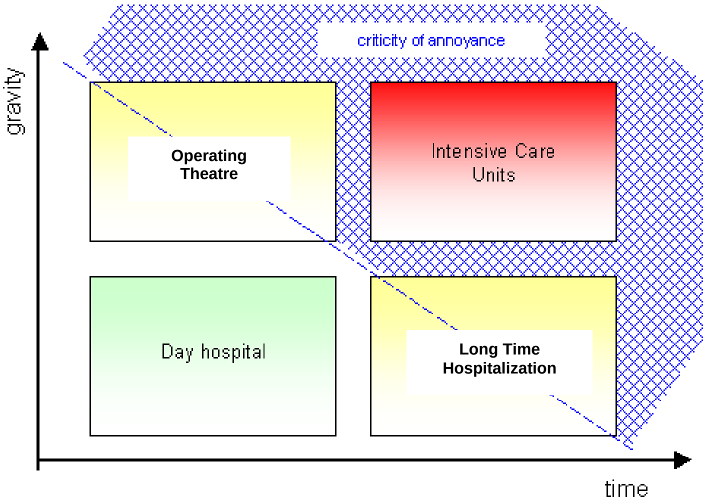
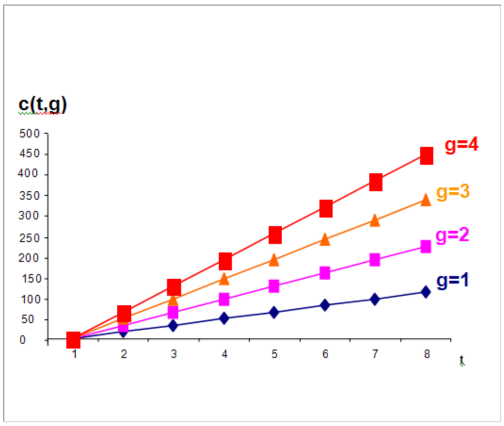


Figure 2: Hospital critical areas and activities

In Table 3 the intensive care case study results are shown: the best fitting correlation pattern is represented by the linear trend equation.

Table 3: Index **c** in the intensive care unit case study

<table>
<tr><td colspan="9">**LINEAR - INTENSIVE CARE UNIT**</td></tr>
<tr><td>**parameters**</td><td></td><td></td><td></td><td colspan="5" rowspan="4"></td></tr>
<tr><td>measured noise exposure level</td><td>**Nt**</td><td>LAeq</td><td>32,0</td></tr>
<tr><td>time annoyance coefficient</td><td>**Mt**</td><td>(0,…,1)</td><td>0,5</td></tr>
<tr><td>gravity annoyance coefficient</td><td>**Ng**</td><td>(0,…,1)</td><td>0,5</td></tr>
<tr><td>**equation**</td><td colspan="8">$c\,(t,g) = N_t\,M_t\,t + N_g\,g$</td></tr>
<tr><td colspan="4" rowspan="10"> </td><td>**variables**</td><td colspan="4">gravity index **g** (APACHE II)</td></tr>
<tr><td>hospitalization time **t** [days]</td><td>**1**</td><td>**2**</td><td>**3**</td><td>**4**</td></tr>
<tr><td>**0**</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>**1**</td><td>16</td><td>32</td><td>48</td><td>64</td></tr>
<tr><td>**2**</td><td>32</td><td>64</td><td>96</td><td>128</td></tr>
<tr><td>**3**</td><td>48</td><td>96</td><td>144</td><td>192</td></tr>
<tr><td>**4**</td><td>64</td><td>128</td><td>192</td><td>256</td></tr>
<tr><td>**5**</td><td>80</td><td>160</td><td>240</td><td>320</td></tr>
<tr><td>**6**</td><td>96</td><td>192</td><td>288</td><td>384</td></tr>
<tr><td>**7**</td><td>112</td><td>224</td><td>336</td><td>448</td></tr>
</table>

THE SIX SIGMA APPROACH

Six Sigma is a quality management philosophy and a business discipline that aim to improve processes so that they could perform at their highest possible levels. In healthcare buildings levels of performance can be related to environmental comfort indexes, like the acoustical one described in the previous paragraph.

Six Sigma is based on two models, depending upon the nature of involved processes. The improvement of existing processes follows a DMAIC (Define, Measure, Analyze, Improve and Control) model; the development of a new process follows the DMADV (Define, Measure, Analyze, Design and Verify) model.

A case study, see Luchsinger (2008), illustrates how a healthcare Six Sigma project team applied the DMAIC approach to improving the care of open-heart surgery patients by reducing their post-operative length of stay. The result was an increase of the quality of patient care while reducing the average length of stay and costs for patients.

Another case study, see Bertels (2007), leads with the problem of excessive cycle times for processing orthopedic disability claims. As a result of Six Sigma approach the total cycle time was reduced from an average of seventeen to less than six days, variation was reduced by 60 %, and less than 16 % of all cases took longer than ten days.

It’s possible to adapt the critical area models described above to the Six Sigma approach. For example, the fishbone diagram in Figure 3 represents the quality pattern of the possible contributors to post-op length of stay. It is used in identifying all the potential contributors to process variations, a fundamental principle of the Six Sigma approach.

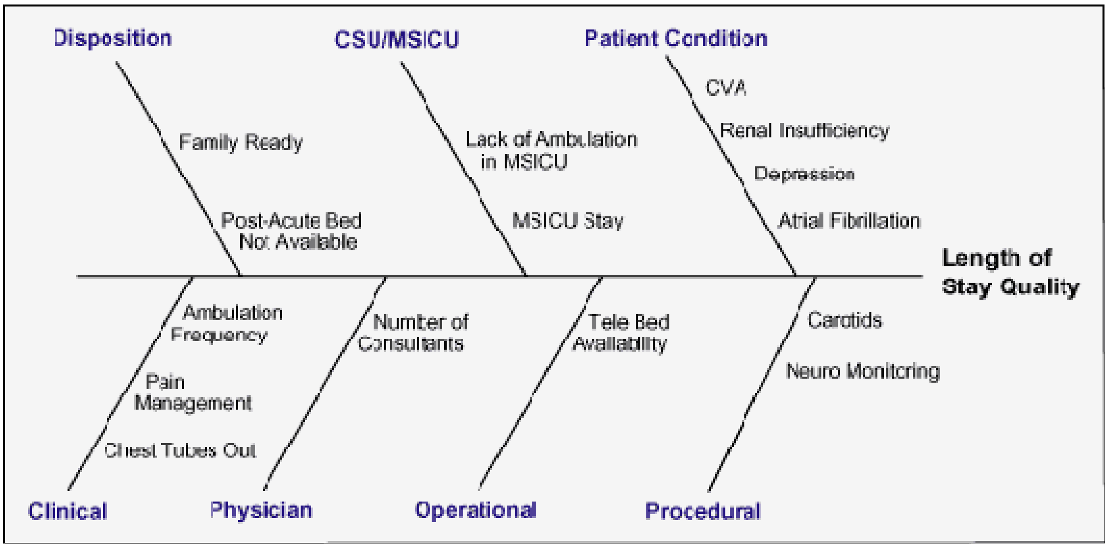


Figure 3: Six Sigma approach for post operation length of stay

CONCLUSIONS

Hospitals and healthcare buildings can be considered as sensitive noise receiver collectors. Human activities and internal services give heavy contribution to the lack of acoustical comfort. Even in a brand new hospital, important systems of sources stand in the building area, in the roof and in the surrounding area.

The analysis of the acoustic quality of the building has to be performed taking into account that the effects of noise on patients depend primarily on the length of staying and consequent exposition as well as on the severity of illness.

A priority scale about the possible interventions for noise reduction can be obtained. In this paper a model of criticity, and a consequent priority scale based upon time and severity has been proposed.

Six Sigma approach has already been applied with success to healthcare projects, including indexes similar to the ones described in this paper.

The next step could be a Six Sigma definition (re-definition) of designing procedures for healthcare buildings. The noise factor seems to be one of the easier to be modeled.

The final result would be a best practices guide that not only designers, owners, and administrators, but also final users (like operators) can use to build and maintain high quality and high performance hospitals.

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